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Real Options: Risk-free and Market Interest Rates

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Abstract
Traditionally, present worth is computed with a single interest rate. However, the real options literature includes examples where "first" costs are discounted using a continuous risk-free interest rate while later revenues are discounted using discrete market interest rates. This begs the questions of why, how common, and how important are these interest rate assumptions?

This paper analyzes real option articles in leading finance journals and *The Engineering Economist* to (1) establish the range of assumptions that have been used, (2) estimate their relative frequencies, and (3) illuminate the difference in approaches between finance and engineering economy. This paper also analyzes a realistic delay option example. Sensitivity analysis allows us to examine when and if the difference in interest rate assumptions leads to different recommendations and what aspects of the problem drive changes in those recommendations. In conclusion we make recommendations regarding the use of multiple discount rates for determining NPV.

Key Words: Real Options, Engineering Economy, NPV, Interest Rates

Introduction

Discounted cash flow techniques are the most widely used methods for determining the value of a project. These techniques include net present value (NPV), internal rate of return (IRR), and others. NPV is determined by discounting forecasted future net revenues by a required rate of return, as in equation (1):

$$NPV = -I_0 + \sum^{N} \frac{CF_t}{(1+r)^t} \quad (1)$$

where

I_0 is the investment
CF_t is the future cash flow
r is the discount rate
t is the time period
N is the number of time periods

The required rate of return is often the weighted average cost of capital (WACC) or a higher 'hurdle rate' that is the WACC adjusted for various risk factors. The WACC is defined in equation (2). Some textbook presentations separate equity into preferred stock, common stock, and retained earnings. However, as described in Eschenbach and Whittaker (2003), the presence of treasury stock commingles equity so that it cannot realistically be separated.

$$WACC = w_d k_d (1-T) + w_e k_e \quad (2)$$

where

w_d is the weighting for debt
k_d is the before-tax cost of debt (in percent)
T is the tax rate
w_e is the weighting for equity
k_e is the cost of equity (in percent)

Despite being widely embraced by academia and industry, discounted cash flow (DCF) analysis has been criticized by proponents of real options analysis for biasing evaluators toward conservative conclusions (Copeland & Antikarov, 2003). In reality, management has options of making changes during the life of the project, especially during the early stages. Real options analysis is a tool intended to place a value on the managerial flexibility in future choices (Trigeorgis, 1993). The option creates an expanded net present value, defined as (Trigeorgis, 1996):

$$\text{ENPV} = \text{NPV} + \text{Option Value} \quad (3)$$

There are five variables that are involved in determining an option value: S_0, present value of future net revenues; X, investment costs; t, the time horizon; r, interest rate and σ, volatility of the project's rate of return. Note that the first four of these are the same as those used to determine NPV.

It is at this stage that different authors make different assumptions about interest rates. For example, S_0, the present value of future net revenues is often calculated with a discrete hurdle rate; while r is often a continuous, risk-free rate applied to the cost to build the project.

The Black-Scholes pricing model (Black & Scholes, 1973) can be used to determine the value, C, of a simple call option. This model has been expanded to include the cost of waiting (W) as shown in equations (4), (5), and (6). The necessity of and models for including waiting costs are presented in Eschenbach et al. (2009a). Note that most of these variables are the same as those used in the net present value equation.

$$C = \left(S_0 - W\right)\phi(d_1) - Xe^{-rt}\phi(d_2) \tag{4}$$

$$d_1 = \frac{\ln\left(\left(S_0 - W\right)/X\right) + \left(r + \sigma^2/2\right)t}{\sigma\sqrt{t}} \tag{5}$$

$$d_2 = d_1 - \sigma\sqrt{t} \tag{6}$$

where $\phi(d_x)$ is the cumulative standard normal distribution of d_x

Alternatively, the option value can be computed using binomial lattices, as detailed in Mun (2006).

Copeland and Antikarov (2003) developed a four-step process to carry out a real options analysis. The steps include:

1. Compute the present value without flexibility using discounted cash flow.
2. Model the uncertainty using decision trees.
3. Identify and incorporate the managerial flexibilities.
4. Conduct real options analysis.

With this definition, it is clear that options analysis does not replace net present value; it builds on it.

Future net revenues must be discounted to the present time. Costs may occur in the future, and if so, must also be discounted to the present. An appropriate discount rate must be determined for use in the discounting calculation. Some authors have recommended using market rates (hurdle rates) for discounting future net revenues, while using risk-free rates for discounting costs. This is often done when computing option values, whether using the Black-Scholes equation or binomial lattices. This paper focuses on the recommendation of using multiple discount rates for determining the net present value.

In this paper, we examine the question of what interest rates should be used to discount future net revenues and future costs. The finance and engineering economics literature is first reviewed, along with practitioner guidebooks. A realistic deferral option is analyzed using two approaches to determine the impact of using multiple hurdle rates in the fashion recommended. The issue is discussed, and recommendations are made regarding the use of multiple discount rates for determining NPV.

Literature Review

In engineering economics, accepted projects generally meet or exceed some threshold of growth. This ensures that the company will grow at, or better than, its expected rate. We use the term minimum attractive rate of return, or MARR, because it is the minimum rate of growth that a company will accept from its invested projects (Hartman, 2007). The MARR is greater than the cost of capital as the MARR must allow for sufficient returns to pay back the cost of capital and still support firm growth.

The nominal rate of return that we would expect on an investment is made of three parts: risk-free return, inflation, and a risk premium (Park, 2007). The *real* rate of return is the two parts of return over inflation. It is common for costs and revenues to be estimated in constant-dollar terms. If this is done, then market interest rates must be real rates of return over inflation, not nominal rates.

If a firm wants to increase its growth rate, then it will want to fund projects that have a higher level of return. Many firms impose a risk premium as a hedge against risk (and as a hedge against overly optimistic claims of project managers!), requiring high rates of return for high-risk projects. This higher interest rate is commonly called the hurdle rate.

There are several views within the engineering economy literature regarding how MARR should be determined (Eschenbach & Allen, 2002). These include basing MARR on the cost of capital, or basing MARR on the opportunity cost (ranking projects either on internal rate of return or present worth). While this debate is outside the scope of this paper, it can be said that the engineering economy literature offers multiple methods of determining a MARR, without consensus on a single method. However, this literature does generally support use of a *single* interest rate to evaluate a project.

The financial literature clearly bases the chosen interest rate on the weighted average cost of capital. However, different projects have different risks, and a project's hurdle rate may be chosen to reflect the risk of the project, not the risk of the firm's average project as reflected in its composite WACC (Brigham & Houston, 2009). A firm's WACC is used to evaluate most projects, but if a project has an especially high or low risk, the hurdle rate may be adjusted up or down to account for this risk.

Many firms traditionally use a single hurdle rate based on their firm's WACC. Some firms have multiple divisions, and sometimes these different divisions define very different investment risks from each other. In this case, a single WACC or a single hurdle rate may not be appropriate for every division within the firm. The finance literature has long held that many firms use multiple hurdle rates (Brigham, 1975), so there may be division specific hurdle rates, sometimes called a Divisional WACC (Titman & Martin, 2008). Many companies adjust for project risk by defining risk types, and assigning a unique hurdle rate to each type of risk. For example, a replacement project may carry a hurdle rate of 6.5%, a cost reduction project 7.0%, and a new product may require a risk-adjusted rate of 14.0% (Higgins, 2009). Specific projects may also be assigned a unique hurdle rate based on risk and how the project is financed. This process is not universally supported (Reimann, 1990).

Myers (1974) recommended an "adjusted present value" (APV) to differentiate the appropriate discount rates between high and low risk projects within a firm. Myers recommended one discount rate for cash flows and another for "side effects" such as tax shields (the tax benefit of using debt). In essence, rather than combining all forms of financing into one WACC, he recommends breaking out the different discount rates and calculating the present worth of the individual parts (using separate discount rates), then adding them together to determine the APV. Over the years, this approach has received modest support in the literature (Ezzell, 1984; Trigeorgis, 1993). Luehrman more recently recommended using APV for valuing operations and projects (Luehrman, 1997a; Luehrman, 1997b).

Luehrman expanded on this APV concept within the real options framework. When determining the NPV of a real option problem, he recommends discounting future net revenues by a market-based hurdle rate, while discounting costs by the risk-free rate (Luehrman, 1998). This is similar to what is usually done within the option value calculation.

This recommendation has appeared in books. Mun (2006) continues this recommendation of discounting costs by the risk-free rate while discounting revenues by a higher market-based rate within the same NPV equation. Park (2007) also recommends this technique.

However, this approach of using multiple discount rates for determining a project's NPV has not received wide acceptance. This recommendation has not been found in *The Engineering Economist*, nor has it appeared widely in the finance literature.

In Lewis, Eschenbach, and Hartman (2009b) we address the question of discrete versus continuous compounding. For clarity that issue is not addressed here.

Before we try to reach a conclusion on the theoretical soundness of these various choices, let us examine a case study to see how much this might matter.

Case Study

An oil exploration company is considering leasing a plot of land and drilling an oil well. The well is expected to have characteristics that are typical of this company's projects, and the equipment sizing, outputs, and costs are well understood. The characteristics of the project are shown in Exhibit 1.

The first step is to determine the NPV of the project. Note that in addition to the initial investment of $57 million, there will be an additional salvage cost of $10 million at the end of the project to return the site to its original condition (which will be discounted as a future cash flow). The output of the well will begin in Year 2, but the output declines at 15% per year. The well will produce for seven years before it is shut down. Cash flows are shown in Exhibit 2. In reality, original investment costs may be spread over multiple years, and *work-overs* and other investments may increase later recoveries and extend the life. But this model is a good conceptual model of the initial decision.

Exhibit 1. Oil Well Project Information.

First cost	$57 million
Oil price	$50/bbl
Oil price volatility	35%
Project volatility	To be determined
Salvage cost	$10 million
Output, yr 1, 10^6 bbls/yr	0.60
Well depletion rate/yr	15%
Operating costs	$10/bbl
Hurdle rate	16%
Risk-free rate	5%
Project delay	Up to 2 years

Exhibit 2. Project Cash Flows, millions of dollars.

Year	Invest Now	Delay (up to 2 years)
0	−57.00	0
1	0	0
2	24.00	−57.00
3	20.40	0
4	17.34	24.00
5	14.74	20.40
6	12.53	17.34
7	10.65	14.74
8	9.05	12.53
9	−10.00	10.65
10		9.05
11		−10.00

There is an additional cost if the project is delayed: the cost of the lease. The lease is considered an investment cost, part of the cost of delaying the project. This lease cost is bounded by the option value; if the actual lease cost is greater than the ENPV, then the option should not be pursued.

NPV for delayed project. The NPV can be determined using equation (1) given the hurdle rate of

16% and assuming that there is no delay in the project. If the project were started now, it would have an NPV of −$0.46 million. The well is not worth starting given the current price of oil.

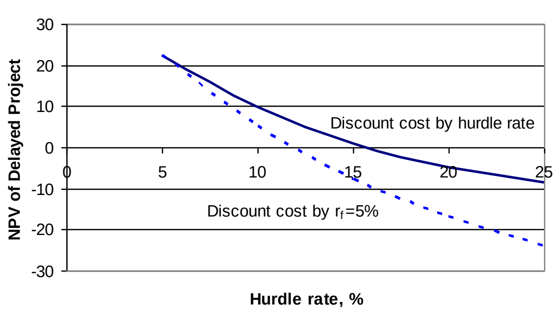
The company has several options. First, it could invest in the project; however, the NPV is negative, making this unattractive. Second, the company can abandon the project, as suggested by the NPV. Third, the company could keep the project open by paying a lease on the property, investing later only if prices increase enough in the future to make investment economical. By paying the lease, the company can pay a relatively small premium (the lease) to preserve the option of future investment. The question is: how much should the company be willing to spend to keep the option (the project) open by paying a lease? This is a real option problem; the firm should be willing to pay up to the project's ENPV to keep the option open.

Part of the evaluation is to determine what the NPV of the project would be if it were delayed for two years. Rather than determining the option value here, we will focus first on the NPV of the delayed project.

Traditional methods dictate that we discount all of the cash flows, including the investment, found in the "Delay" column of Exhibit 2. One discount rate of 16% is used. This provides a delayed NPV of −$0.34 million. If the first costs are discounted by the risk-free interest rate of 5%, this NPV becomes −$9.68 million, which is considerably lower.

The effect of the discount rate on the NPV of the delayed project is shown in Exhibit 3. Discounting the first cost by the risk-free rate has a significant negative effect on the present worth of the project, leading to ultra conservative recommendations. Even though the investment costs are near time zero and will not be discounted much, they are barely discounted with the low rate. Normally, we increase the rate on future returns to discount them because they are risky. This is the opposite. The risk premium on investment flows is eliminated with the lower rates because they are negative, keeping the NPV more negative.

Exhibit 3. Effect of interest rates on NPV.



While very few would believe an argument that the future cost to drill an oil well is risk-free, it is certainly much less risky than the returns for drilling the well which depend on an uncertain geology and an uncertain future price of the oil.

Real option calculation for delay example. Some of the first applications of real options analysis involved natural resource projects. This is largely because there was a foundation for determining project volatility: commodity price fluctuations. As most of the examples we've analyzed with real options have led to questions about one or more points of "standard practice," this example has been selected as the best hope for a "good" example of the effectiveness of real options. The example presented here is analyzed along the lines of conventional practice. We do have unanswered questions about this approach, but it still is an effective example to describe conventional practice.

Before the option value can be determined, the volatility of the project must be estimated. Project volatility is defined as the standard deviation of the rate of return of the project. We have only one source of uncertainty: the price of oil, which has a standard deviation of 0.35. Project volatility is usually higher than the volatility of any input, so a value greater than 0.35 would be a logical initial estimate.

The most widely used approach is the logarithmic present value of returns (Copeland and Antikarov, 2003). (For a detailed discussion of volatility, see Lewis, Eschenbach, and Hartman (2008).) The oil price is assumed to follow a lognormal distribution, since the price cannot fall below zero. The oil prices are correlated 90% from year to year as the price in one year will tend to follow the price of the preceding year. Without correlation, each year's price would vary independently of preceding prices. Without correlated oil prices, there is no actionable volatility due to oil prices, and project volatility would be meaningless (Lewis, et al., 2009a).

The Black-Scholes model assumes that prices are lognormally distributed and follow geometric Brownian motion. The binomial lattice method assumes the same, since the validation of the lattice method demonstrates that results approach the Black-Scholes model as the number of time-steps increase. The lognormal and Brownian motion assumptions are two of the difficulties in translating financial options to real options; few real engineering projects have prices which are truly lognormal, including oil prices. In reality, oil prices will be correlated from time period to time period, with long-term prices being mean reverting. Oil prices fluctuations in 2008 were a good example. One way to incorporate the mean reverting nature of the price is to build it into the simulation used for determining volatility; 0% price correlations are

100% mean reverting with the beginning of the next time period, while 100% price correlations are not mean reverting at all. An open question remains as to what is the best value to use. It is difficult to model future oil prices to obtain a meaningful option value.

The details of the volatility calculation are outside of the scope of this paper. The project's volatility is determined to be 0.435 annually, somewhat higher than the 0.35 volatility of the price of oil.

The option value can be determined using the modified Black-Scholes method, shown in equations (4), (5), and (6). The time variable is the time that the project can be delayed. The original Black-Scholes model assumes a European option; one which can only be exercised upon maturity. Here we have an American option; one which can be exercised at any time up to the expiration date. Merton (1973) pointed out that exercising an option early has no value unless there is a dividend (a loss in value due to waiting). However, we have found that all deferral options on real projects have a cost of delay.

Waiting costs can be modeled for a European option without too much difficulty. Delays are known, and lost or deferred cash flows can be modeled based on the delay (Eschenbach, Lewis, and Hartman, 2009a). In the present case, we have an American option, where the firm is waiting for the price of oil to increase to the point where it is economic to pursue the project. What is the waiting cost in this case? It depends on how long the project is delayed, leasing costs, the price of oil when the project is implemented, and what occurs with oil prices in the future.

If the project is not delayed, there is no cost of waiting. If the current case is delayed the full two years, there would be a cost of waiting of $14.52 million (the NPV of the incremental net revenues). A delay of less than two years results in a smaller cost of waiting, but also a smaller option value. The traditional approach is to model the delay to its maximum length of time and use the largest possible option value, inflating the true value of the option.

Substituting our values into equation (5) and (6), we find

$$d_1 = \frac{\ln\left(\left(56.54 - 14.52\right)/57\right) + \left(0.05 + 0.435^2/2\right)2}{0.435\sqrt{2}} = -0.03$$

$$d_2 = d_1 - 0.435\sqrt{2} = -0.64$$

Substituting our values into equation (4), the option value is

$$C = (56.54 - 14.52)\phi(-0.03) - 57e^{-0.05(2)}\phi(-0.64)$$
$$C = 42.02(0.49) - 57(0.905)(0.26) = 7.18$$

The value of the option is $7.18 million. Note that this is the maximum value of the option, assuming the option is kept open for the full two years. In reality, the option will be worth less than this, but given the state of the art, we cannot say how much less. In other words, we don't really know (or trust) the value of the option.

Discussion

As noted earlier, Luehrman, Mun, and Park recommend that multiple interest rates be used for determining the NPV of real options problems. Specifically, they recommend that future net revenues be discounted at a risk-adjusted hurdle rate while future costs be discounted at a risk-free rate. This is not just a real options issue, it is an issue which could impact any discounted cash flow calculation.

Using multiple discount rates is not a new idea, and in general is theoretically supportable. The proposed idea stems from the belief that future revenues are risky while costs are not. We agree that future revenues are risky and should be discounted at an appropriate risk-adjusted interest rate. However, we believe that future costs are also risky, and should also be discounted at a risk-adjusted rate, not at a risk free rate. Determining this rate is outside of the scope of this paper.

Recent work has shown that most companies do not use multiple discount rates. In a 2003 survey, over half of the responding companies use a single discount rate for the entire firm based on WACC, and only 14% of companies use an objective measure of risk to determine their discount rate (Block, 2003). While the academic literature has pursued the idea of multiple risk-based discount rates, the corporate world has not kept pace.

The recommendation of using the risk-free interest rate to discount future costs assumes that future costs are known and are risk free. While costs may be less risky than future revenues, we disagree that future costs are known. Any project manager knows that costs are not absolutely firm, no matter what the budget may say. For example, many projects saw very large increases in projected costs for cement and steel products, which then fell during the recent economic downturn. Similarly, project costs having an energy or transportation component saw high inflation during the first part of 2008 (and did not necessarily see deflated costs as fuel prices fell). These costs were far from risk-free, even those spanning just a few weeks or months. Future costs are clearly not risk-free.

The recommendation of using the risk-free interest rate assumes that money can be borrowed at a risk-free interest rate in order to pay for the project. This is simply not true. A firm's WACC is far higher than the risk-free rate, and we know of no firm that can borrow money for an extended time at the risk free rate. The reason is simple: future costs are not free of risk.

We can support using multiple hurdle rates on a case-by-case basis if there is a justification for doing so. If the firm can identify reasonable risk-adjusted rates for costs and future revenues, there is no reason why the firm should not go ahead and do so.

However, this implies that it might be necessary to separate future cash flows into production costs and revenue streams. For our oil well case, the discount rate for costs would likely be less than the rate for revenues. However, for a new product where the utilization of new capacity is a key uncertainty, then the production costs may be far "riskier" than the unit revenue stream. In either case, we suggest that the time involved in developing this data would likely not be worth the time and effort involved.

We cannot support the concept that future costs are without risk. Delayed projects often have higher costs due to a variety of reasons. Differential inflation is an obvious cause. Delayed projects are often disbanded, and restarting the project often entails bringing in new people and repeating work that had already been done and lost (Eschenbach et al., 2007).

The costs to keep an option open cannot be ignored (Eschenbach et al., 2009b). Mineral and petroleum leases can require annual payments before development. Product development that is shelved can require continuing licensing fees for patents. R&D that is open (but not actively moving to the next stage) still requires personnel and lab expenses. Land that is undeveloped will still have property taxes. Keeping an option open is not free.

Students in engineering economy courses are usually taught to use a single interest rate for determining present worth. This is the most common method within both finance and engineering economy courses. It is also the method most widely used in large U.S. firms. The use of a single discount rate should continue to be the basis for teaching discounted cash flow analysis.

Conclusions and Recommendations

Discounting project costs using a risk-free rate while discounting future net revenues at a higher hurdle rate can have a dramatic influence on the NPV of a project. Discounting costs at a lower interest rate decreases the present worth of a project.

Use of the risk-free rate for discounting costs assumes that future cost estimates are free of risk. This is simply not true in the world of real engineering projects. This practice also assumes that money can be obtained at the risk-free rate, which is also not true for firms that are not banks.

Unless there are clear reasons for having multiple rates (and there may be), we recommend that the engineering economy community continue with the current practice of discounting both costs and revenues with one appropriate discount rate. We do not recommend the use of the risk-free rate for discounting project costs, whether they are in a real option or traditional discounted cash flow analysis context.

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